Challenges in modelling of non-equilibrium transport processes in high-pressure thermal plasmas

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Résumé

Promoted by large-scale industrial applications of thermal plasmas, considerable advances have been achieved during past decades in theoretical and experimental investigations on the complicated fundamental processes in arc discharges. Previous results indicated that the interaction between the arc and electrode plays a significant role for producing and sustaining the arc discharges in which the sheath region with extremely small spatial scale and large parameter gradient deviates from the local thermodynamic and chemical equilibrium states and charge neutrality condition [1,2]. Due to the small spatial scale and large parameter gradients within the sheath, there exists a strong electric field inside the sheath which leads to complicated potential, current density and heat flux distributions. Meanwhile, experimental measurements are hardly employed to study the effect of the sheath behavior on the characteristics of the high-pressure thermal plasmas. Therefore, numerical simulation has become a powerful tool for investigating the non-equilibrium transport processes in thermal plasmas with the fast development of the computer hardware and software.

In this study, we first review our recent work on the numerical studies concerning the non-equilibrium transport processes in a thermal plasma system. In the first case, a two-dimensional non-equilibrium model combining a thermal-chemical non-equilibrium fluid model for the quasi-neutral plasma region and a simplified collisionless sheath model for the electrode sheath region was employed to reveal the non-equilibrium synergistic effects in an atmospheric argon arc plasma [3]. In the second case, a 1D3V (one-dimensional in space and three-dimensional in velocity) implicit particleincell Monte Carlo collision (PIC-MCC) method was used to study the cathode sheath also in an atmospheric direct-current arc plasma [4]. Based on these modeling results, the sheath characteristics obtained from the analytical model in the first case and those from the kinetic model in the second case are compared with each other. It is shown that, on one hand, both the kinetic model and the analytical model can provide the information on the heat flux, current density and temperatures along the plasma-sheath and sheath-electrode interfaces; while on the other hand, only the kinetic model can provide the spatial profiles of the potential, species number densities, and in particular, the energy distributions of electrons and ions inside the sheath. The predicted spatial distributions of the preceding key plasma parameters indicate that the plasma inside the sheath is in a complete non-electrical-thermal-chemical equilibrium state, and the energy distribution functions of electrons and ions both deviate from the Maxwellian distributions. In our opinion, it is a big challenge to investigatge the synergistic non-equilibrium mass, momentum and energy transport processes based on a combined hydrodynamic and

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PIC-MCC model for a thermal plasma system in future research.

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